Impact of climate change on sewer storage tank performance

Impact du réchauffement climatique sur les performances des bassins de retenue

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RÉSUMÉ

Cet article présente une études des effets potentiels du réchauffement climatique sur la conception et les performances des bassins de retenue. Le scénario de l'IPCC - émissions moyennes/élevées- est utilisé pour générer une prédiction à long terme du niveau de précipitation à Londres. Les résultats indiquent une augmentation du nombre d'évènements météorologiques causant le remplissage du réservoir de 35%, ainsi qu'une augmentation des volumes moyens de 57%. Une méthode d'estimation du volume de retenue nécessaire est développée et décrite. Il apparaît que des volumes de retenue significativement plus larges seront nécessaires pour maintenir le même niveau de protection contre les crues.

ABSTRACT

The paper describes a study of the potential effects of climate change on the design and performance of sewer storage tanks. A long-term synthetic rainfall time-series has been derived based on the IPPC medium-high emission scenario for a case study in London. Results indicate a 35% increase in the number of storm events that cause filling of the tank and a 57% increase in the average volume of storage required. A method to estimate the required future storage volume for any given return period has been developed and described. Indications are that significantly larger storage volumes will be required to maintain the same level of flood protection.

KEYWORDS

Climate change, flooding, sewers, storage.

1 INTRODUCTION

Flood storage tanks are an important and ubiquitous part of sewer networks in urban areas. They are typically designed to ameliorate downstream flooding problems and/or limit overflows into the aqueous environment. Perhaps the most important factor influencing the design and performance of storage tanks is rainfall, as it is this that determines the quantity of stormwater to be collected and detained. Climate change looks likely to affect the nature of rainfall in the future, and will therefore affect the performance of storage tanks (Dale *et al.,* 2002; Ashley *et al*., 2005; Grum *et al*., 2006). This has implications for existing storage tanks and the plans for future tanks. In order to extend the life span of current in-situ tanks, it may be necessary to increase the storage volume provided so that they maintain the required performance criteria. As regards proposed tanks, climate change needs to be considered as part of the design process to produce reliable tanks that can perform well throughout their entire design life.

This paper details the result of a study on the performance of a sewer flood storage tank under present day and future, climate affected rainfall and the resulting implications.

2 CLIMATE CHANGE AND RAINFALL

The Hadley Centre's Europe regional climate model (RCM) has been used to derive climate predictions for the UK, based on four IPPC (2001) scenarios and three time horizons (2020s, 2050s and 2080s). Whilst the output has produced a wide range of climate predictions, a number of general conclusions on rainfall can be reached (Butler & Davies, 2004; Hulme, *et al.,* 2002). Generally, the climate will become warmer leading to increases in annual precipitation by up to 10 % by the end of the century, with increases of up to 35% occurring in winter under the high emissions scenario. Almost the whole of the UK is expected to be drier in the summer, with greatest decreases (up to 50% in the high emissions scenario) in the southeast. Heavy winter rainfall will become more frequent, with intensities that are currently experienced around once every two years becoming between 5% (low emissions) and 20% (high emissions) heavier by the 2080s. Storm events in the summer will become more intense and more frequent.

In order to study the predicted impact of climate change on sewer storage tanks, it is clear that the rainfall data for design and analysis needs to be updated. One simple option to achieve this is to apply an 'uplift' to current design storms (Dale *et al.,* 2002; Ashley *et al*., 2005). The future design storm is produced by applying a fixed percentage increase to rainfall intensities across the entire event. The advantage of this method is its simplicity; it can easily be applied to design storms and time-series rainfall.

A second option is to increase the 'peakedness' of storms to account for climate change. However there is a number of difficulties with implementing this procedure including time-series rainfall having more than one peak, extracting peakedness information from the wide range of events found in time-series rainfall and altering peakedness for different return periods.

2.1 UKWIR CL/10 project

A third more thorough and theoretically justified approach is that developed by Onof *et al.* (2002), under the the UK Water Industry Research CL/10 project (Dale *et al.,* 2002), which takes a broader approach than simply looking at design events. The Hadley RCM was used to produce two sets of data for 7 different regions in the UK. The first set (the control series) was produced by running the RCM under current climate conditions. The second set (the anomaly series) was generated under assumed climate change conditions. The difference between these two sets is visible from Figures 1 and 2, in terms of increase in total volume of rainfall. Note how the top line (Glenlee) is significantly higher in Figure 2 than Figure 1.

Onof *et al.* (2002) have developed an hourly stochastic rainfall generator *Balerep*, which they used with results from the RCM under both current and future conditions. The current rainfall generated by *Balerep* is calibrated against the RCM control series for all seven locations using the following statistics:

- Point mean of 6-hourly intensities / Areal mean of 6-hourly intensities;
- Point variance of 6-hourly intensities / Areal variance of 6-hourly intensities;
- Point autocovariance lag 1 of 6-hourly intensities / Areal autocovariance lag 1 of 6-hourly intensities;
- Point variance of 12-hourly intensities / Areal variance of 12-hourly intensities;
- Point proportion of dry periods in the 6-hourly data / Areal proportion of dry periods in the 6-hourly data;
- Point proportion of dry periods in the 24-hourly data / Areal proportion of dry periods in the 24-hourly data.

Once this calibration was carried out against the control series, it was possible to use *Balerep* to generate future rainfall based on the anomaly series. The steps involved in this time-series approach are:

- Estimate statistics of 6-hourly rainfall
- Downscale these to point statistics
- Estimate *Balerep* model parameters
- Generate hourly rainfall time-series at gauged points
- Disaggregate them to 5 minutes

The outcome of the work was to produce a well-developed rainfall dataset extending one hundred years into the future for the seven UK locations as used in the RCM, and including the potential effects of climate change.

Balerep has been shown to reproduce many features of the hourly precipitation signal, both in terms of the properties of the rainfall intensity and of the wet-dry structure (Onof *et al.,* 2002). However, there are a number of shortcomings to the method of producing predicted future rainfall events in the above manner. It has been observed that the generation of extreme events tends to be underestimated as return periods increases. However, for the purposes of sewer storage tank design, the return period concerned is relatively low and the underestimation in these cases is also low.

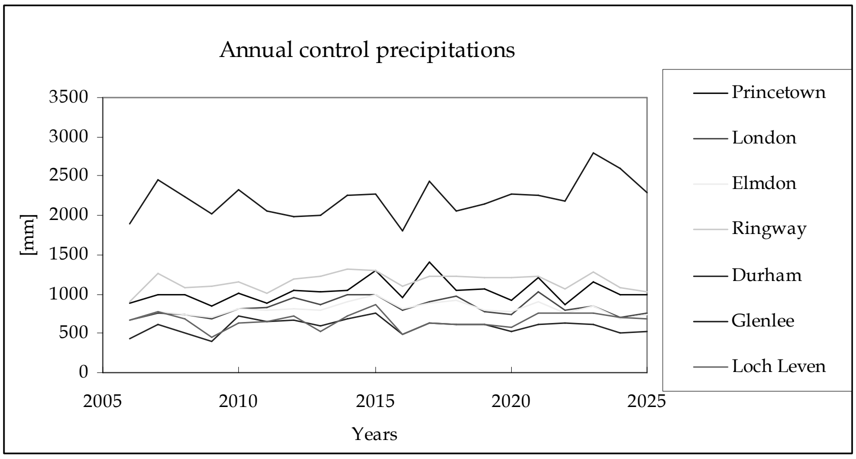

Figure 1. Control Annual Rainfall Depths (Onof *et al.*, 2002)

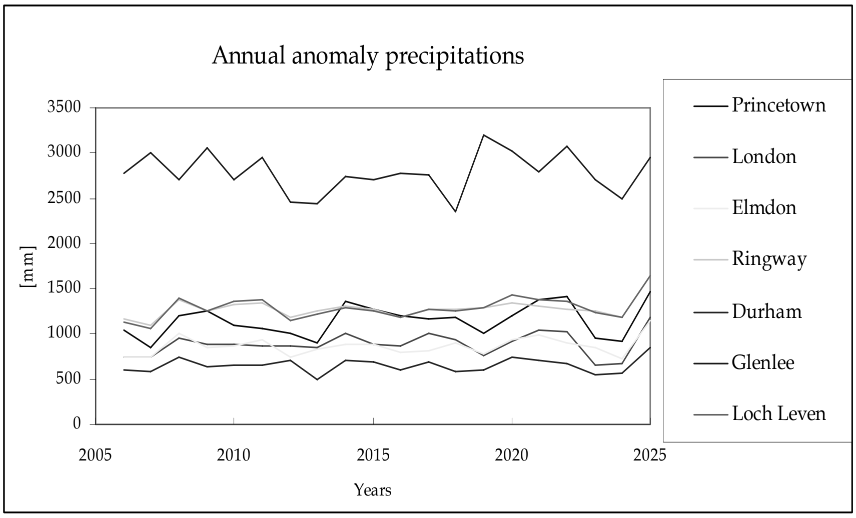

Figure 2. Anomaly rainfall depths (Onof et al., 2002)

2.2 Using Generated Future Rainfall

A rainfall dataset developed for the London area was used in this study. Two sets of 5-minute rainfall data were extracted from the complete one hundred year series. The first is the initial ten years from the complete set and is termed 'current rainfall'. The second is the last ten years is designated 'future rainfall'. In order to reduce the size of these input files, zero depth and other minor storm events were removed leaving a series of more significant individual events to be used as input to a sewer model. This procedure speeds up the modelling time and is valid given our main interest is the times when a significant volume of rainfall-runoff enters the sewer system loading the storage tank.

3. CASE STUDY

The site used for this study is in an area of North London that has been the site of some flood alleviation work by Thames Water in the last few years. A new storage tank has been built to alleviate persistent flooding in a number of properties. Details of the site are given in McEntee (2004).

The sewer network and storage tank have been modelled using Wallingford Software's InfoWorks CS. This is well-known software giving integrated hydrological and hydraulic simulation, a solution of the full St. Venant equations using a Priessmann 4-point scheme, inbuilt rainfall generation capabilities, interactive views of output data and selected animated presentations. The model was calibrated and verified based on local rainfall measurement using tipping bucket rain gauges and flow measurement using in-situ depth and velocity monitors at key locations.

The tank volume was sized based on Flood Studies Report rainfall (NERC, 1975). The critical storm was the M15-240 winter event – that is a storm of 240 minutes duration with a return period of 15 years. It is designed to fill by gravity during storm events and then empty by means of a pumping system.

4. MODELLING THE EFFECTS OF CLIMATE CHANGE

The two datasets, current and future, were run through the InfoWorks sewer model. The current rainfall set (1980-1990) consists of 1072 separate events labelled GRP_0001 to GRP_1072. The future rainfall set (2080-2090) consists of 770 separate events labelled GRF_0001 to GRF_0770. By observing the simulated level of water in the tank for each storm event it is possible to study the performance of the tank for the present period and also its likely performance in the future. Having run simulations for the entire set of rainfall, the critical storms were identified for further study. Table 1 summaries the results from the modelling process.

Factor	1980s	2080s
Total number of storms	1072	770
Number of storms requiring storage	75	101
Fraction of storms requiring storage (%)	7.0	13.1
Average storage volume (m^3)	286	431
Number of tank failures	1	3

Table 1. Storage comparison for current and future rainfall

A storm requiring storage is defined as an event where the tank fills by any amount during the storm. While the 1980s ten year period contains more storms, a smaller proportion of these actually require storage. The average storage volume is the average of the storage required for storms where some level of storage is required i.e. the non-critical events are disregarded. The design of the tank assumed that there would be some level of filling of the tank about eight times a year. From these results, 75 filling events are shown to occur during the first ten-year period, which confirms the initial design. However, there is a 35% increase in the number of filling events that take place, from 75 events for the current ten-year period to 101 events over the future ten-year period. There is a 57% increase in the average volume of storage required from 286 m^3 in the 1980s up to 431 m^3 for the 2080s. Thus, the tank is expected to fill up more often and to a greater degree in the future.

The most critical result is the number of tank failures. A failure is defined as an event where the tank is filled completely and excess volumes are forced downstream with the possibility of flooding. For the 1980s period there is only 1 tank failure for the entire 10-year period. This again confirms the initial design based on a 1 in 15 year design storm event. However, the future rainfall events cause 3 tank failures for this ten-year period of rainfall; a significant decrease in the tank performance.

4.1 Increasing storage volume

When a failure event occurs due to tank overfilling, excess volumes of water are spilled from a large number of manholes. It was considered unwise to attempt to sum all the lost volumes from the manholes downstream as they are the result of a combination of effects including flows from the other branches of the network not only due to the failure of the storage tank. In order to calculate the excess volume which should be provided by the storage tank in order to cope with the event, it was decided to increase the size of the tank in increments and run the failure event until the tank did not fill entirely. In practice this would be possible by increasing the dimension of the tank either in plan or elevation or both. However, to increase the height of the tank, it would be necessary to reduce the level of the tank base. Performing this operation on the InfoWorks model would lead to complication with the levels of the outflow pipes and the pumps. By altering to the system in this way we would lose the ability to carry out a reasonable comparison. So, in this work the plan area only was adjusted.

Initially the tank had a plan area of 85.4 m^2 with an effective storage volume of 2263 m^3. Increasing the plan area to 200 m^2 leads to an effective volume of 5348 m^3, which provides enough additional storage for three of the four failure events. From the maximum level in the upsized tank it is possible to calculate the increased storage required to cope with each of the original failure events. This area upsizing still fails to hold the entire volume of excess water for one of the failure events and a further increase in tank plan size (to 400 m^2) is needed for this. The additional volumes required are summarized in the table 2.

Table 2 suggests that an increase in storage of some 500 m^3 will reduce the number of tank failures in the future to the same level as that at present. However, event GRF_0734 is large and a more standardised procedure for accounting for such large events is required.

Event	Max Level (m)	Area (m^2)	Volume (m^3)	Δ volume (m^3)
GRP_1030	46.27	200	4254	1990
GRF_0276	38.70	200	2740	476
GRF_0091	36.89	200	2378	114
GRF_0734	40.96	400	6384	4120

Table 2. Extra Storage Volume Required for Failure Events

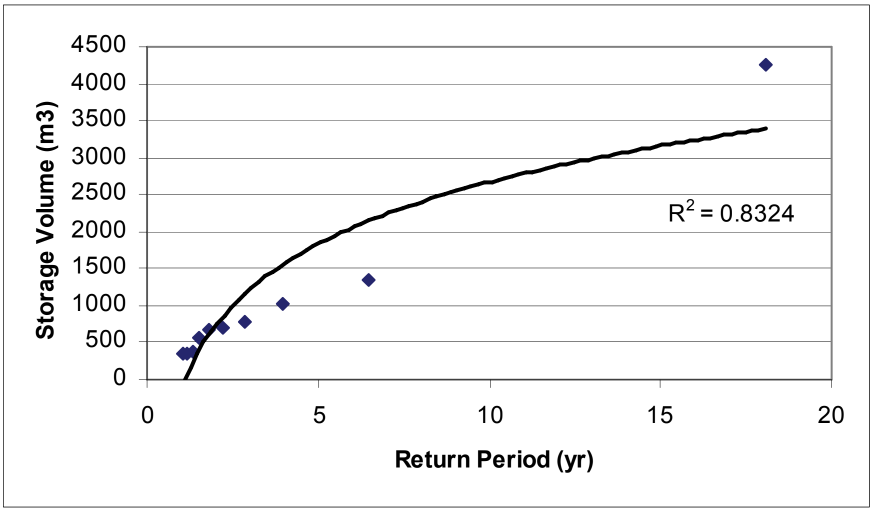

Figure 3. Return period for annual maximum current storage requirement

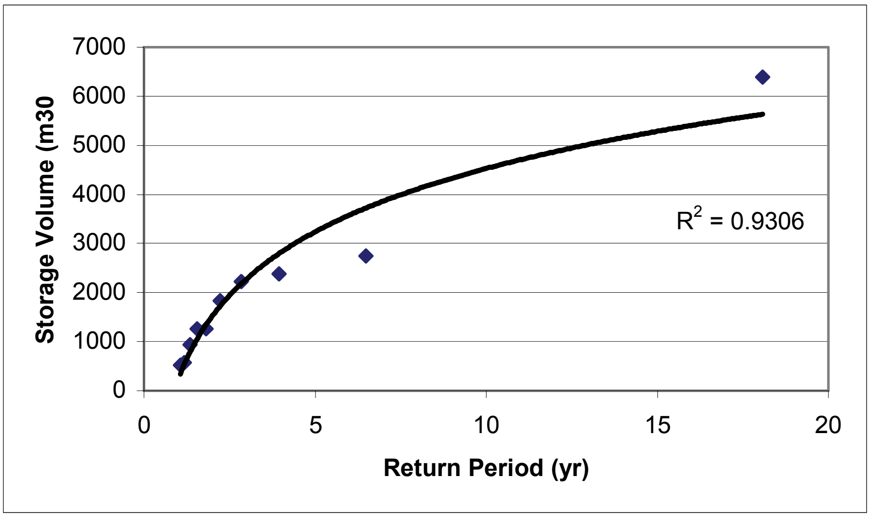

Figure 4. Return period for annual maximum future storage requirement

Annual maximum storage volumes required for both current and future cases have been calculated, ranked and assigned return periods using the standard Gringorten plotting position formula. By plotting annual maximum storage requirement against return period, a (logarithmic) best fit line can be estimated and the volume required to store a 15-year return period event (or any other return period) easily interpolated (Figures 3 & 4). Figure 3 infers that for current rainfall, the tank should hold a volume of 3,200 m^3, while Figure 4 suggests that for future rainfall, the tank should hold a volume of 5,300 m^3. This a significant increase in the storage volume required to predict against the 15 year return period event, but accounts for the effect of GRF_0734.

5. CONCLUSIONS

The effects of climate change on the performance of a sewer storage tank have been comprehensively modelled using an appropriate future rainfall dataset. Results indicate that the performance of the tank suffers considerably when climate change is taken into account. The model predicts a 35% increase in the number of storm events that cause filling of the tank and a 57% increase in the average volume of storage required. A method to estimate the required future storage volume for any given return period has been developed and described. Indications are that significantly larger storage volumes will be required to maintain the same level of flood protection. Note, however, in addition to the usual uncertainties of model building and verification, we have additionally here the issue of using synthetically generated rainfall, both for present conditions and more importantly for future conditions. Climate change itself is hugely uncertain and the results from this work are based on just one scenario: medium-high emissions. Still the results indicate problems ahead and the potential means to solve them.

6. ACKNOWLEDGEMENT

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